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Restoration of Delta Streams: A Case History and Conceptual Model

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BACKGROUND AND PURPOSE: Delta streams, forming in the floodplains of large river systems, are widespread throughout the United States. Delta streams are most prevalent in the Mississippi Embayment, also referred to as the lower Mississippi River Basin. The alluvial floodplain deposits are typically rich in organic material. Consequently, most delta streams have been altered through intense agricultural activities and flood control measures. Low water, excessive sedimentation in smaller delta streams, and the accumulation of pesticides such as DDT are the consequences of these anthropogenic disturbances resulting in dominance of tolerant fish species. Characteristics of tolerant fish assemblages include adaptations to low dissolved oxygen and high pulses of suspended solids, no direct requirements for clean, firm substrates for spawning, and ability to live in shallow, slackwater pools for extended periods. Although degraded delta streams are prevalent in the United States, attempts have been made to restore habitat conditions as part of ecosystem restoration or mitigation of flood control projects.

One such project occurred in the Upper Steele Bayou System (USBS) in west central Mississippi. The USBS encompasses 282 square miles in the Yazoo Delta of the lower Mississippi River basin. All of the streams in the USBS lie within a predominately agricultural landscape and were highly degraded from low water and sedimentation. Fishes were sampled in 1990, and again in 1994, to establish baseline conditions and evaluate potential impacts and mitigation requirements of a proposed flood control project (Killgore and Hoover 1991). However, restoration measures were also incorporated into the plan. Between 1995 and 2001, seven weirs were constructed; 66 drop pipes were placed in surrounding agricultural lands next to the streambank to reduce erosion; and approximately 63 miles of channel enlargement, cleanout, and selective snagging were completed that removed soft, unconsolidated substrates and improved flow conveyance (Figure 1). These were recognized as watershed-level benefits to aquatic communities. Consequently, habitat and fishes of the USBS were re-sampled repeatedly from 2000 to 2005 to document the current status of the fish assemblage and compare these data to collections made in the early 1990s.

On September 24, 2005, Hurricane Rita caused major flooding in the Yazoo Delta during a period of low water conditions. Water levels were elevated with a concomitant increase in biological oxygen demand caused by influx of organic debris, which resulted in widespread hypoxia throughout the delta. Fish kills were reported, low

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dissolved oxygen levels were measured (e.g., below 1.0 mg/l above the Steele Bayou Structure 1 week after the hurricane), and a black, flocculent film covered substrates in smaller streams two months after the hurricane. Additional sampling was conducted post-hurricane to continue evaluating long-term trends in the ichthyofauna and evaluate effects of this atypical, possibly catastrophic event, in the USBS. Overall, the USBS was sampled over a 15-year period and these data are summarized in this article to describe long-term trends of the fish assemblage associated with ecosystem restoration in delta streams.

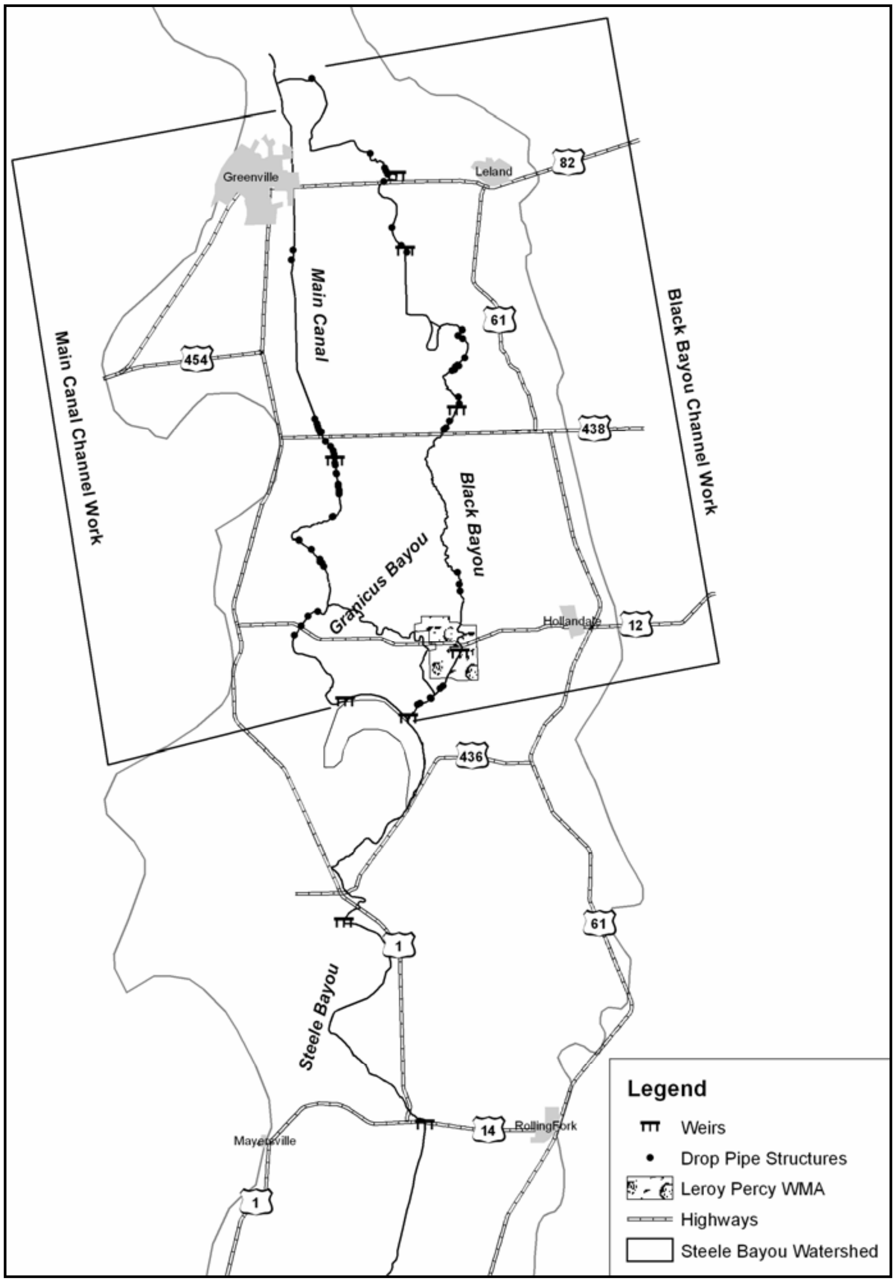

Figure 1. Map of Upper Steele Bayou System showing location of sampling sites, weirs, drop pipe structures, and stream segments that were channelized/cleared.

METHODS:

Field Protocol. Sampling methods and locations pre- and post-project were comparable (Killgore and Hoover 1991). The geographic limits of the sampling area included the western portion of the Yazoo Delta between Greenville and Rolling Fork, MS. Four streams in the USBS were sampled before and after completion of the project (Figure 1): Black Bayou at Leroy Percy State Park (above and below weir at Highway 12); several locations on Main Canal, Granicus Bayou (an extension of Main Canal); and Steele Bayou at the Highway 14 weir. Black Bayou, Main Canal, and Granicus Bayou are tributaries of Steele Bayou. A total of 12 sites were repeatedly sampled in these streams during a 15-year time interval, although some sites were sampled only 2 or 3 times, resulting in a total sample size of 44. Due to the hurricane, additional sampling was conducted at three historic sites in November 2005 and June 2006: Main Canal, Black Bayou, and Steele Bayou Highway 14 weir. Sampling was consistent over the years, and included seining for fishes and measurements of physical habitat and water quality variables.

Fishes were collected by seining (Figure 2). Using a 10-ft seine with 3/8-in. mesh, standard effort was 10 hauls stratified among all apparent physical habitats and distributed equitably throughout a homogeneous reach. Habitat was quantified concurrently with fish sampling. A cross-sectional transect was established at a representative point (usually mid-length of the reach sampled), at which stream width was measured. At 10 equidistant points, depth and water velocity were measured using a wading or stadia rod and Marsh-McBirney water velocity meter, respectively. Turbidity was measured with a Hach 2100P turbidimeter. Temperature, conductivity, dissolved oxygen, and pH were measured with a Hydrolab multi-parameter water quality probe. Depth of soft substrate was measured by pushing the stadia rod into the stream bottom near the middle of the channel.

Figure 2. Seining is an effective technique for evaluating fish communities in delta streams.

Data Analyses. Data were statistically analyzed using statistical analysis software (SAS) (SAS Institute 1999). Data are presented for four separate series of collections: pre-project (early 1990's), post-project (early 2000's), hurricane (2005), and post-hurricane (2006). Temporal changes in physical habitat were described using mean values and ANOVA. Fish community complexity was evaluated using measures of fish diversity (i.e., expected number of species, species richness, Shannon function). Responses of physical habitat and individual species were evaluated using catch-per-unit-effort and percent composition.

Temporal change in species richness of the fish community (all samples pooled) was evaluated using rarefaction (Ludwig and Reynolds 1988, Magurran 1988). Rarefaction compensates for different fish abundances among groups of data. For a composite series of samples (or a large sample), it expresses total number of species expected from a random subsample of given size (e.g., 500 fish). Since species richness of individual collections is influenced by the number of individuals obtained (i.e., more species with more individuals), rarefaction provides direct comparisons of subsamples of equal size. Construction of rarefaction curves (expected number of species for subsamples of increasing size) provides additional information. Slopes of the left-hand side of the curve (i.e., smaller subsamples) and right-hand side of the curve (i.e., larger subsamples) allow inference of equitability of abundance among species (i.e., evenness) and estimates of sampling effort required for detection of additional species. Rarefaction analysis was performed using Analytic Rarefaction 1.3 software (Holland 2003) developed from analyses described by Raup (1975) and Tipper (1979).

Temporal change in species composition of individual collections (assemblages in each stream) was evaluated using two indices: species richness, S (i.e., number of species observed in that sample) and the Shannon function, H' (i.e., which incorporates richness and evenness components of diversity). It is calculated as:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \qquad (1)$$

in which S = number of species and p_i = proportion of the sample comprised by each species, i. Values of H' can range from approximately 0 (domination by a single species) to lnS (all species equally abundant). In most natural communities, H' ranges from 1.50 to 4.50 (Magurran 1988). Values observed for stream fish collections using the field protocol typically range from 0.50-3.00.

DDT concentrations in fish tissue reported prior to 1990 represent concentrations in whole fish collected and analyzed by the Mississippi Department of Wildlife and Parks and the U. S. Fish and Wildlife Service. Fish tissue DDT data reported after 1990 represent concentrations in skinless fish fillets (e.g., channel catfish, buffalo, crappie) collected and analyzed by the Mississippi Department of Environmental Quality and the Engineer Research and Development Center in Vicksburg, MS. Organochlorine pesticides (DDT) were analyzed using gas chromatography equipped with electron capture detectors according to EPA SW-846 Method 8080 and Method 8081A (U.S. Environmental Protection Agency (USEPA) 1986). Results are reported as the sum of the DDT, DDE, and DDD concentrations.

HABITAT IMPROVEMENTS: Channel enlargement and clearing removed the soft, unconsolidated substrate in almost 60 stream miles, which was identified as one of the primary impediments to recovery of benthic fish species. Prior to the project, soft substrate depth averaged 2 ft based on personal observations (i.e., not measured pre-project). Stable, packed substrates less than 1 ft in depth were observed during post-project fish sampling at most sites (Table 1). Turbidity levels vary according to the amount of rainfall and can exceed 200 NTUs after storm events. Drop pipes were intended to reduce sediment inflows and stabilize streambanks. Although turbidities continued to fluctuate post-project, this variable was significantly ($p<0.05$) higher pre- than post-project suggesting reduced sediment inflows (Table 1). In addition to benefits of drop pipes, weirs were constructed that provided longer periods of elevated water levels. Average depth at base flows (minimal or no water over weirs) increased 1 to 2 ft at most sampling sites after weirs were constructed. Together, these habitat changes contributed to a more diverse fish fauna.

Table 1
Physical Habitat in the Upper Steele Bayou, Mississippi, Before and After Construction of the Project[1]

Habitat Parameter	Pre-Project	Post-Project	Hurricane	Post-Hurricane
Temperature, ºC	15.9 (7.7)	24.4 (3)	12 (0.6)	30.9 (2.6)
Conductivity, µmhos/cm	263 (209)	408 (208)	390 (135)	108 (373)
Dissolved oxygen, mg/l	8.2 (1.8)	5.8 (2.4)	8.0 (1.0)	6.7 (3.2)
pH	7.3 (0.2	8.2 (0.6)	7.4 (0.2)	7.9 (0.5)
Turbidity, NTU	147 (69)	57 (79)	37 (23)	20 (6)
Depth, ft	2.9 (2.0)	4.3 (2)	3.1 (1.5)	3.6 (1.4)
Width, ft	104 (85)	123 (45)	107 (19)	103 (26)
Discharge, cfs	33 (26)	26 (67)	16 (7)	9 (17)
Soft sediment depth, ft	>2.0[2]	0.5 (0.5)	0.2[3]	0.7 (0.9)

[1] Pre-Project: Oct 1990 and December 1994, n=9. Post-Project: 2000-2004, n=22, all autumn samples except two in April 2001. Two months after Hurricane Rita - Nov 2005, n=5. Post-Hurricane - May 2006, n=5. Numbers are mean values (and standard deviation).
[2] Estimated, not measured.
[3] Only one measurement taken.

Water quality (temperature, dissolved oxygen, turbidity) fluctuates in response to discharge. Mean discharge was actually higher during sampling of pre-project conditions compared to other periods, which may have decreased water temperature and increased dissolved oxygen and turbidity. However, delta streams are typically characterized by relatively low dissolved oxygen (3-5 mg/l) and the fish fauna are adapted to periodic hypoxia (< 3 mg/l) (Hoover and Killgore 1998). Therefore, changes in dissolved oxygen are not a particularly relevant variable to evaluate long-term trends in habitat quality.

Turbidity also rapidly increases with discharge, but based on the maximum values measured during any given period, turbidity was higher pre-project (253 NTU) and post-hurricane (303 NTU) compared to the two other periods (<60 NTU) (Table 1). Higher turbidities pre-project are likely due to the unconsolidated substrates in the stream bed that were eventually removed and erosion from agricultural fields where drop pipes were eventually installed. Sampling occurred two and ten months after the hurricane. Although mean turbidity was within an acceptable range, the actual color of the water was stained black from the elevated concentrations of dissolved organic matter. Similarly, accretion of the black, flocculent film that covered substrates was likely caused by decomposing

organic debris. Ten months after the hurricane, the film was not noticeable suggesting complete decomposition or affects of periodic flushing flows that occurred during spring 2006.

BENEFITS TO THE FISH COMMUNITY

Community Complexity. Post-project species richness was higher than pre-project species richness (Figure 3). In either series, for any number of fish greater than 500, expected number of species was greater than 16, with post-project values 3-5 species higher than pre-project values. Community was depauperate immediately following the hurricane, less than 9 species, and elevated afterwards, more than 24 species. Curve shapes were similar among all four series of collections suggesting similar structure among the four series. Curve slopes for small subsample sizes (< 250 fish) were high, indicating numerical dominance by several species. Slopes rapidly decreased at moderate subsample sizes (250-500 fish) indicating substantially lower abundances by a greater number of species. Slopes were very low at very high sample sizes (> 1500 fish), indicating extreme rarity of several species.

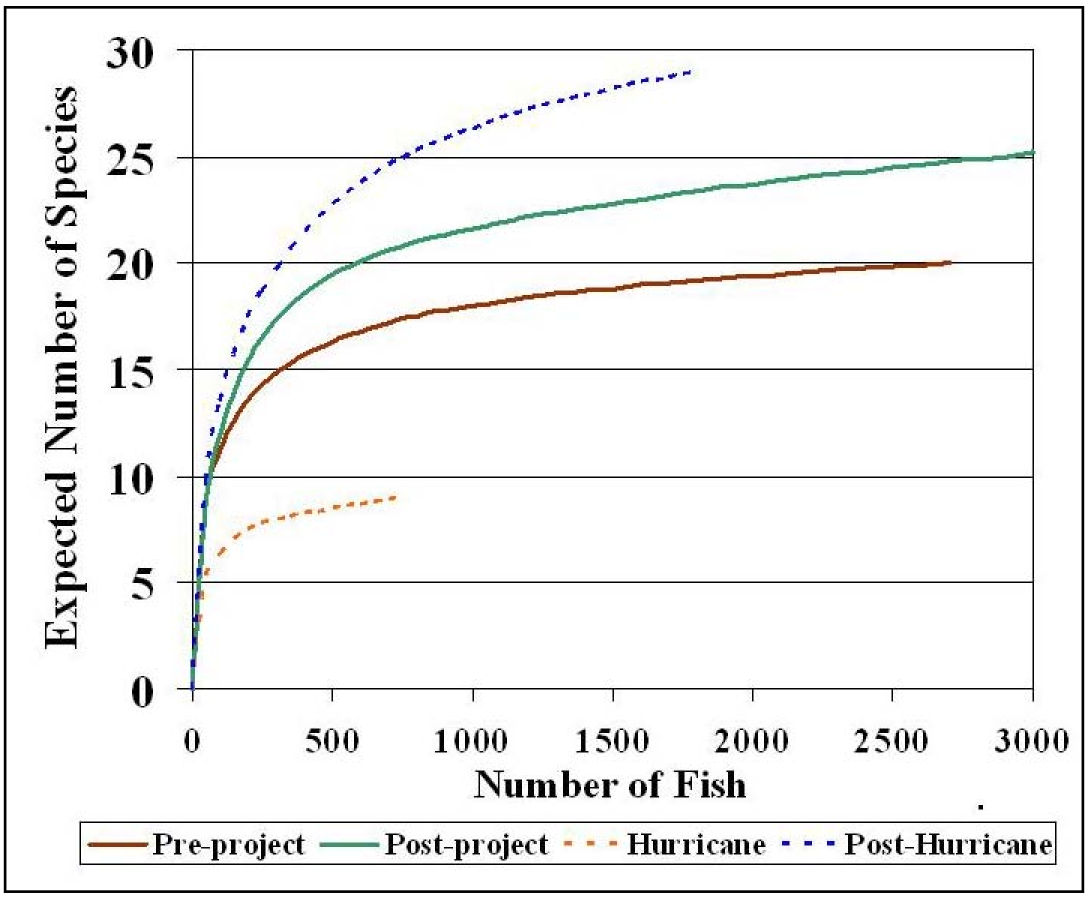

Figure 3. Rarefaction curves for fish communities in the Upper Steele Bayou System over a 15-year interval relative to a flood control/restoration project that was completed in the late 1990's. Sampling occurred pre-project (1990 and 1994), post-project (2000-2004), 2 months following Hurricane Rita (2005), and 10 months post-hurricane (2006).

Increased species richness and/or diversity of fish assemblages (individual samples) were observed in three of the four streams after project completion based on the 2000-2004 samples (Figure 4). Excluding Black Bayou, species richness was higher in the study streams post-project. The greatest increase over time occurred in Steele Bayou where species richness was over 50 percent higher post-project (Figure 4). Considering that the Steele Bayou Hwy 14 weir is the most downstream sampling site, cumulative effects of habitat improvements in the upper watershed should be reflected in the lower reaches. Diversity was not substantially different between the two time periods (1990 – 1994 versus 2000 – 2004), although the actual mean value was higher (1.34) after project completion than before (1.0). Diversity values for littoral fish communities in the lower Mississippi Basin rarely exceed 2.5, and those high values usually only occur in unimpaired streams. Black Bayou showed the least change in diversity and richness. Considering all streams in the USBS prior to construction, the lower reach of Black Bayou had the greatest amount of riparian vegetation comprised mostly of mature trees. These buffer strips likely contributed to higher diversity of the fish fauna pre-project (see "A Restoration Plan for Delta Streams" below), and the fish assemblage varied little over the course of the study.

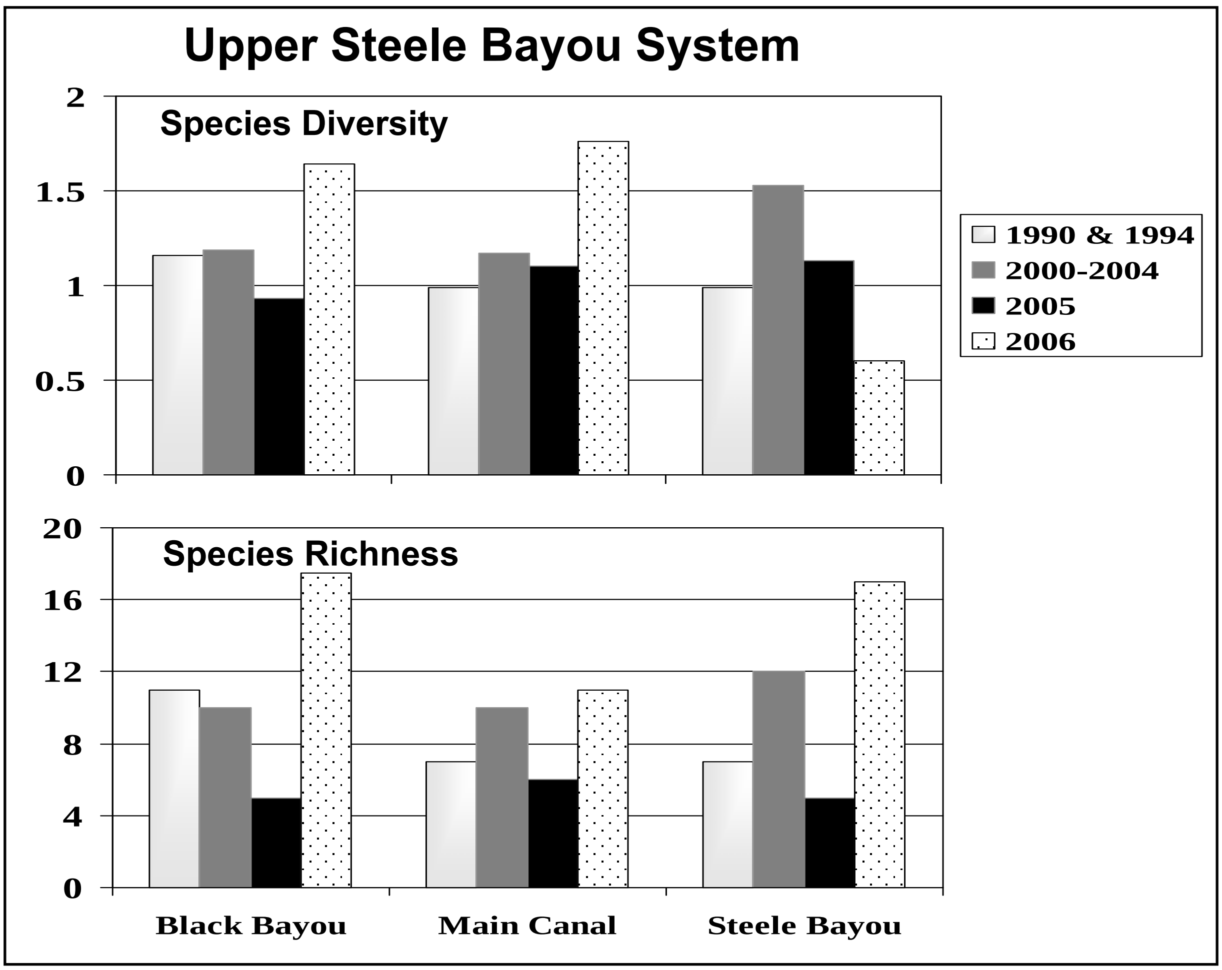

Figure 4. Changes in mean fish species diversity (Shannon function) and species richness (number of species) in the Upper Steele Bayou System over a 15-year interval relative to a flood control/restoration project that was completed in the late 1990's. Sampling occurred pre-project (1990 and 1994, n=10), post-project (2000-2004, n=24), 2 months following Hurricane Rita (2005, n=5), and 10 months post-hurricane (2006, n=5).

Impacts of the hurricane to fish assemblages were evident, but recovery was rapid. Aquatic invertebrates and fish have been reported to rapidly recover from catastrophic events in other stream systems as well (Matthews 1986, Mefee and Minckley 1987). Two months after the hurricane, species richness was at the lowest value measured during the past decade in all three streams sampled in the USBS (Black Bayou, Main Canal, and upper Steele Bayou). Diversity was low at all locations, and Steele Bayou was at the lowest value measured since sampling began at this location in 1994. Highest species diversity value (1.7) was measured in Main Canal 10 months post-hurricane. In Steele Bayou, richness was significantly ($p<0.05$, df=7) lower pre-project and 2 months post-hurricane, but recovered to a high of 17 species 10 months after the hurricane (Figure 4).

Community Composition. More than 35 fish species were documented from USBS (Table 2). The community was dominated taxonomically by sunfishes (11 species), and minnows (8 species). Of the 13,426 fish collected during the study, four species comprised more than 80 percent of all fish collected: mosquitofish (35.0 percent), bluegill (28.2 percent), orange-spotted sunfish (11.8 percent), and red shiner (9.1 percent). These species are all tolerant of degraded water quality and habitat. Other tolerant species that were moderately abundant (1-3 percent) were: warmouth, inland silverside, green sunfish, and white crappie. Many species were lower in abundance (0.1-1 percent). These included all species considered intolerant of degraded water quality, habitat, or both: threadfin shad, dollar sunfish, golden topminnow, tadpole madtom, bantam sunfish, and speckled chub. Several species were rare (<0.1 percent). These included several intolerant species such as pugnose minnow and pirate perch. They also included species of commercial importance, gars and buffalos and species of recreational importance, white bass and largemouth bass.

Table 2
Mean Number and Percent of Total Number (in brackets) of Fish Collected by Species per Sampling Event in the Upper Steele Bayou, Mississippi[1]

Scientific Name	Common Name	Pre-Project N=10	Post-Project N=24	Hurricane N=5	Post-Hurricane N=5	Total Number N=44
Family Lepisosteidae						
Lepisosteus oculatus	Spotted gar		<1[<1]			4
L. osseus	Longnose gar				<1[<1]	1
L. platostomus	Shortnose gar	<1[<1]				1
Lepisosteus spp.	Juvenile gar				<1[<1]	2
Family Clupeidae						
Dorosoma cepedianum	Gizzard shad	<1[<1]	3.79[1.12]		9.2[2.52]	141
D. petenense	Threadfin shad *		3.46[1.02]			83
Family Cyprinidae						
Cyprinella lutrensis	Red shiner	21.7[7.98]	40.58[12.02]		145[1.59]	1220
C. venusta	Blacktail shiner				1.2[<1]	6
Cyprinus carpio	Common carp	<1[<1]	<1[<1]		1.8[<1]	19
Macrhybopsis aestivalis	Speckled chub *		<1[<1]			13
Notemigonus crysoleucas	Golden shiner	4.1[1.51]	<1[<1]		7.2[1.97]	85
Notropis atherinoides	Emerald shiner		<1[<1]			2
N. buchanani	Ghost shiner		1.08[<1]			26
Opsopoeodus emiliae	Pugnose minnow*		<1[<1]		<1[<1]	2

(Continued)

Table 2 (concluded)

Scientific Name	Common Name	Pre-Project N=10	Post-Project N=24	Hurricane N=5	Post-Hurricane N=5	Total Number N=44
Family Catostomidae						
Ictiobus bubalus	Smallmouth buffalo		<1[<1]		1.6[<1]	9
I. cyprinellus	Bigmouth buffalo				<1[<1]	2
I. niger	Black buffalo		<1[<1]			1
Ictiobus spp.	Juvenile buffalo				<1[<1]	1
Family Ictaluridae						
Ameiurus melas	Black bullhead	<1[<1]	<1[<1]		<1[<1]	9
A. natalis	Yellow bullhead		<1[<1]		3.8[1.04]	20
Ictalurus punctatus	Channel catfish	8.4[3.09]	1.42[<1]		6.4[1.75]	150
Noturus gyrinus	Tadpole madtom *	3.5[1.29]	1.38[<1]	<1[<1]	<1[<1]	72
Family Aphredoderidae						
Aphredoderus sayanus	Pirate perch	<1[<1]				2
Family Fundulidae						
Fundulus chrysotus	Golden topminnow *		2.33[<1]	3.6[2.31]	1[<1]	79
Family Poeciliidae						
Gambusia affinis	Mosquitofish	110.9[40.79]	84.67[25.07]	59.8[38.38]	251.2[68.86]	4696
Family Atherinidae						
Menidia beryllina	Inland silverside	<1[<1]	6.42[1.90]		9.6[2.63]	203
Family Moronidae						
Morone chrysops	White bass				<1[<1]	1
Family Centrarchidae						
Centrarchus macropterus	Flier *				<1[<1]	2
Lepomis cyanellus	Green sunfish	10.0[3.68]	1.5[<1]	2.4[1.54]	1.6[<1]	156
L. gulosus	Warmouth	3.5[1.29]	6.29[1.86]	1.6[1.03]	2[<1]	204
L. gul. X marg. X macro.	Hybrid sunfish		<1[<1]			1
L. humilis	Orangespotted sunfish	81.6[30.01]	25.54[7.56]	13[8.34]	18[4.93]	1584
L. macrochirus	Bluegill	16.8[6.18]	130.46[38.64]	73.2[46.98]	23.6[6.47]	3783
L. marginatus	Dollar sunfish *	2.0[<1]	2.5[<1]		<1[<1]	81
L. megalotis	Longear sunfish *	1.1[<1]		1.6[1.03]	<1[<1]	22
L. symmetricus	Bantam sunfish *		1.71[<1]	<1[<1]	3.2[<1]	59
Lepomis spp.	YOY sunfish		16.54[4.90]			397
Micropterus salmoides	Largemouth bass		<1[<1]		1.6[<1]	15
Pomoxis annularis	White crappie	3.9[1.43]	2.46[<1]		1.4[<1]	105
P. nigromaculatus	Black crappie	<1[<1]	2.29[<1]		9.8[2.69]	110
Family Percidae						
Etheostoma gracile	Slough darter *		<1[<1]			1
Family Sciaenidae						
Aplodinotus grunniens	Freshwater drum	1.5[<1]	1.5[<1]		1[<1]	56
Total Number of Species		**20**	**32**	**9**	**31**	**92**
Total Number of Fish		**2719**	**8104**	**779**	**1824**	**13,426**

[1] Sampling events occurred before construction of the project (Pre-Project: Oct 1990 and December 1994), after construction (Post-Project: 2000-2004; all autumn samples except two in April 2001), two months after Hurricane Rita (Nov 2005), and 10 months after the hurricane (Post-Hurricane: May 2006). All fish were collected with a 10-ft seine. Species considered intolerant of degraded water quality or habitat (sensu Jester et al., 1992) are indicated with an asterisk (*).

This pattern of abundance among species (few very abundant, most intermediate in abundance, several rare) is characteristic of many communities and represents an “interplay of many more-or-less independent factors, multiplicatively compounded” rather than a single limiting environmental resource or competition-based interplay among similar species (Ludwig and Reynolds 1988). Temporal changes in occurrence and abundance of most of these species indicate how the community responded to habitat improvement and the hurricane.

The pre-project fish community consisted of 20 species, whereas 30 species occurred post-project. Increase in richness was due principally to pre-project absence and post-project colonization by intolerant species: threadfin shad (3.5/sample, post-project), golden topminnow (2.3/sample), bantam sunfish (1.6/sample), ghost shiner (1.1/sample), and speckled chub (0.5/sample). Large numbers of inland silverside (6.4/sample), and threadfin shad indicate substantial zooplankton populations, golden topminnows and bantam sunfish, the availability of structurally complex habitats (vegetation, woody debris) and persistent slack water, and ghost shiner and speckled chub, moderate water velocities. In addition, benthic species such as slough darter were collected for the first time indicating firmer, more stable substrates. Commercial fishes were documented in the system (buffalo) and nest-building sunfishes increased (warmouth, bluegill, dollar sunfish). Largemouth bass were collected only post-project. Largemouth bass are rarely collected in Yazoo delta streams, so their presence in USBS, along with other intolerant species, suggests beneficial effects of increased water levels and more stable substrates.

The hurricane caused a significant reduction in overall species richness, to just nine documented species (Table 2). Entire families of fishes disappeared, or nearly disappeared from the streams: shad, minnows, silversides, catfishes, and the larger sunfishes (bass, crappie). This reduction was only short-term, however.

Post-hurricane samples documented 30 species (Table 2). Resiliency of USBS was demonstrated by rapid recovery of many groups and notably by occurrence of new colonists. Only a few post-project species were not observed: threadfin shad, ghost and emerald shiners, and speckled chub. These species may take longer to recover from disturbance, or to recolonize from adjacent waters than other less sensitive or more vagile species: red shiner, channel catfish, inland silverside, largemouth bass, and crappie. In addition, several species, previously not collected, were seen for the first time: blacktail shiner, bigmouth buffalo, white bass, and flier.

Reduction of intolerant species (e.g. threadfin shad, speckled chub, dollar sunfish, bantam sunfish) was the primary reason for lower fish community metrics post-hurricane, likely caused by widespread hypoxia and floods that displaced fish downstream. Anecdotal evidence on commercial catches corroborates impacts, but to larger, more mobile species such as buffalo and catfish.[1] Low diversity in Steele Bayou 10 months after the hurricane was due mostly to the overwhelming numerical abundance of mosquitofish despite high species richness.

Tolerant species persisted throughout the 15-year sampling interval, but their abundance fluctuated widely. The number of intolerant species increased post-project, but the most recent samples (June 2006) showed substantially higher increases in community metrics compared to other time periods.

[1] Personal communication, Bill Lancaster, commercial fisherman, Sunflower, MS.

In summary, long-term habitat conditions and fish assemblages do not suggest greater impairment after the hurricane. On the contrary, recovery may have been facilitated because restoration measures were already in place.

Pesticide Reduction. Channel work has resulted, at least in part, in the reduction of ∑DDT (sum of the DDT, DDE, and DDD concentrations) concentrations in sediment and fish tissue. DDT concentrations were monitored in sediment and fish tissue pre- and post-project (Table 3). Post-project ∑DDT concentrations of both sediment and fish tissue were significantly lower (Black Bayou, $P=0.027$; Main Canal, $P=0.006$). Post-project ∑DDT concentrations in fish tissue collected from Steele Bayou were also lower. Although ∑DDT concentrations in fish tissue have decreased since the pesticide was banned in 1973, average concentrations remained well above the state fish consumption advisory of 1.0 mg/kg. Post-project in 2000 and 2001, 22 fish had DDT tissue concentrations greater than 1.0 mg/kg. By 2005, only 2 fish had tissue concentrations that exceeded the consumption advisory. One was collected in March 2005 before Hurricane Rita; the other was collected in October 2005.

Table 3
Summary of ∑DDT concentrations (sum of the DDT, DDE, and DDD) measured in Steele Bayou sediment and fish tissue.

	Sediment				Fish Tissue		
	Black Bayou		Main Canal		Steele Bayou		
	Pre-	Post-	Pre-	Post-	Pre- [1]	Post- [2]	Post- [3]
Number	13	20	9	19	32	82	42
Mean ∑DDT (mg/kg)	0.085	0.029	0.163	0.052	6.29	0.700	0.212
Median ∑DDT (mg/kg)	0.028	0.016	0.182	0.016	--	0.513	0.096
Max ∑DDT (mg/kg)	0.354	0.106	0.391	0.228	21.0	4.09	1.88
Standard Deviation	0.102	0.031	0.132	0.068	6.18	0.646	0.360

[1] Whole fish collected by Miss. Dept. of Wildlife, Fisheries and Parks and FWS between 1972 and 1988
[2] Fillets collected by MDEQ and ERDC in 2000 and 2001
[3] Fillets collected by ERDC in 2005

A Restoration Plan for Delta Streams. Study of the USBS indicated a shift in species composition from simple to more complex communities and from tolerant to more intolerant fish assemblages. Three principal stressors on fish communities were apparent: extreme low water during late summer and autumn, accretion of soft unconsolidated sediment, and lack of instream structure. The first two stressors were at least partially remedied during the USBS project, leading to increased species richness and greater numbers of intolerant species. A conceptual model was developed to illustrate the expected benefits of management practices on specific groups of fishes in delta streams (Figure 5).

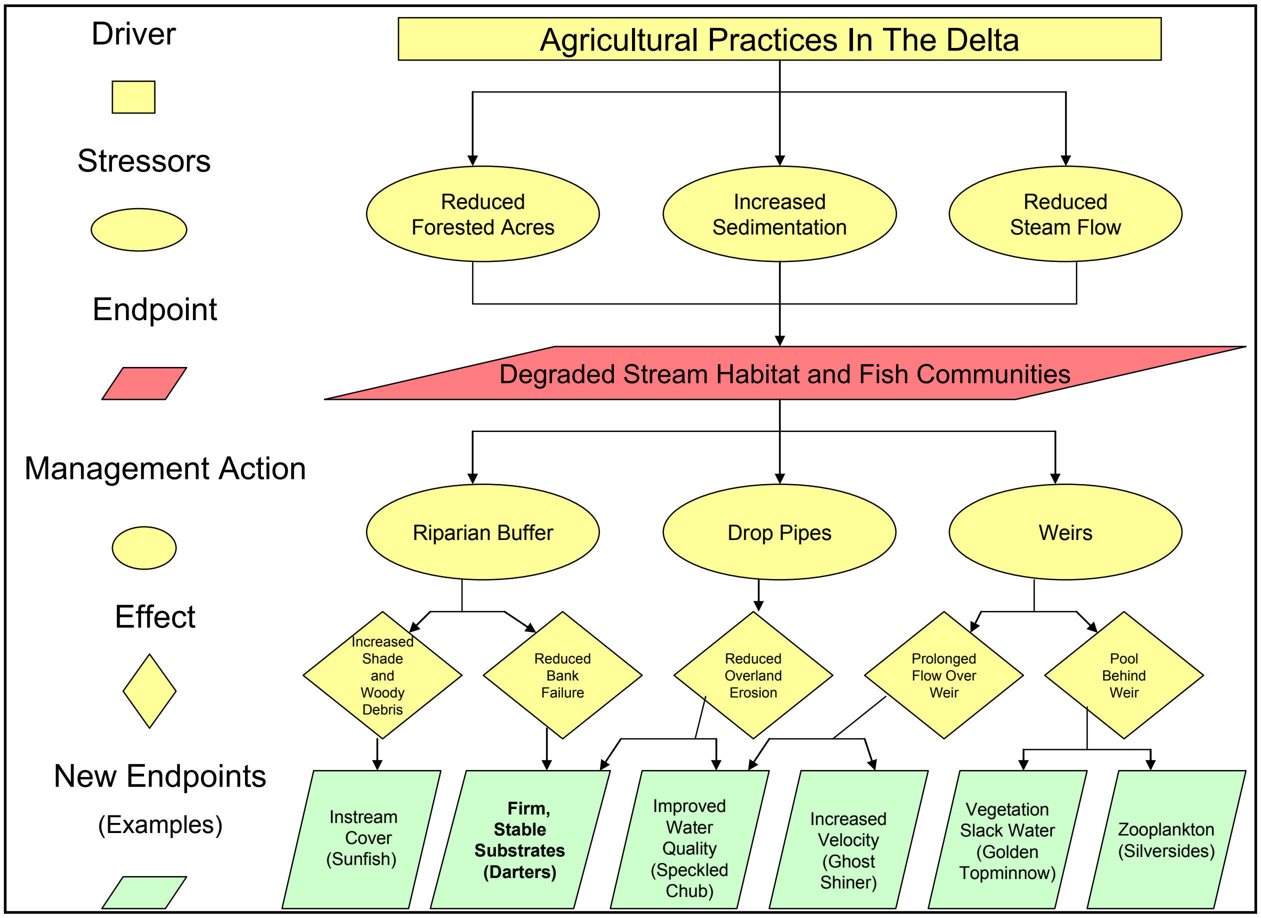

Figure 5. Conceptual model of the expected outcome of restoration measures in delta streams

Water Level Management. Low-crest weirs can be constructed to maintain stable pools during the low-water season (Figure 6). Rip-rap used in weir construction and adjacent bank stabilization provides several benefits. Rock substrates provide sites for attachment of invertebrates that fish feed upon, and the placement of rip-rap creates interstitial spaces used by fish for predator avoidance and spawning crevices. Pooled water facilitated the growth of aquatic vegetation and several taxa of phytophilic invertebrates characteristic of moderate to good water quality (Figure 7). Colonies of bryozoans (i.e., *Pectinatella magnifica*) have been observed. These animals are characteristic of shaded, quiet water, are never found in "markedly polluted conditions," and rarely occur when DO < 30 percent saturation (Pennak 1978). Abundant populations of live-bearing river snails (*Viviparus* sp.) have been documented; these snails are long-lived and sensitive to desiccation and hypoxia.[1] Also common are ramshorn snails (*Helisoma* sp.), which require firm substrates for grazing. Occurrence and abundance of these intolerant invertebrates at weirs in the USBS are direct evidence of prolonged high quality habitat, the restoration value of weirs, and of the recovery of the USBS watershed.

[1] Personal communication, Dr. Barry Payne, Research Aquatic Ecologist, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Figure 6. Low-crest rock weirs with long, tapering slopes provide excellent habitat conditions for delta stream fishes at a relatively low cost.

The tailwaters below weirs are comparable to riffles in streams, and become colonized by rheophilic fish such as madtoms and darters, both of which were collected in the USBS. As a group, rheophilic fish are generally intolerant to anthropogenic alterations (Jester et al. 1992), and have declined in abundance throughout the lower Mississippi River delta. In addition to weirs, water supply projects (e.g., Grand Prairie, AR and Bayou Meto, AR) for irrigation can provide minimum flows to streams. Streams can be used as part of the water delivery system to adjacent agricultural lands, and if some water is dedicated to low flows in the streams, improved biotic conditions can be expected.

Removal of Soft Substrate. Regardless of a dedicated water supply, delta streams will never reach their full potential unless soft sediments are removed, and action is taken to reduce future sediment inflow. For most delta streams, the riverbanks are at a higher elevation than surrounding lands, so runoff moves towards ditches and tributaries. Construction of drop pipe structures in the eroding fields will reduce future runoff (Figure 8). Construction of sediment stilling basins in small ditches and tributaries will also minimize sediment influx. Direct removal of sediments by dredging or drag line is also a viable alternative, and can be combined with some level of flood damage reduction. Sites in the USBS where sediment was removed over 7 years ago and on-farm sediment management was implemented still maintained relatively compact substrates during the latest sampling in 2006. Pesticide levels in fish tissue also decreased, likely due to removal of soft sediments in the streams. Removal of soft sediments will lead to re-colonization of benthic fish (e.g., darters, madtoms) and increased spawning success of nest building species (e.g., sunfishes).

a. Bryozoans (*Pectinatella magnifica*)

b. Snails (*Viviparus* sp. and *Helisoma* sp.)

Figure 7. Bryozoans (*Pectinatella magnifica*) and snails (*Viviparus* sp. and *Helisoma* sp.) are signs of recovery in formerly degraded delta streams.

Figure 8. Drop pipes constructed in agricultural fields reduce erosion and sedimentation in streams.

Riparian Buffer Strips. The third principal stressor, lack of instream structure, can be addressed by planting riparian buffer strips. The width of buffer strips depends on the purpose of the project (Fischer and Fischenich 2000). If the purpose is to benefit fish in delta streams, only a narrow (i.e., less than 30 ft, or two rows of trees) strip is required to provide shade and lower water temperatures along the littoral zone and input of organic debris (Figure 9). Obviously, wider strips will have greater benefits to not only fish, but other groups of wildlife (e.g., amphibians living in fallen trees, birds, mammals). The forested riparian zone benefits fishes and other aquatic organisms from sediment filtration, increased bank stability, periodic food availability, and improvement in the structural complexity of stream channels (Herbonne and Vondracek 2001, Rabeni 1995, Schlosser 1995, Wang and Lyons 1998). As trees mature, limbs and branches will fall into the channel. Some of the woody structure will form larger debris piles, trapping leaves. Macroinvertebrates will quickly colonize the structure and serve as a food source for other aquatic species (Benke and Wallace 2003). Instream structure increases habitat diversity, may pool water or otherwise enhance water quality, and provides velocity refugia and stable substrates for fish and fish prey organisms. As stated earlier, rip-rap is also an excellent form of instream structure in delta streams where hard substrates are generally lacking (Dardeau et al. 1995).

The USBS is an example of a restoration project on a watershed scale with documented environmental benefits (Wohl et al. 2005). Total cost of the project was approximately $35 million, but included a return on investment for flood damage reduction (i.e., cost:benefit = 1.4). The apparent long-term benefits to the aquatic ecosystem further justify these expenditures. It is unrealistic to assume that delta streams can be restored back to pre-settlement conditions. Agricultural activities are too widespread, usually encompassing over 80 percent of the land use. However, this study indicates that focusing on the three primary stressors as part of any water resource project will have beneficial results to the fish community in delta streams.

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Figure 9. A narrow riparian buffer strip will have greater habitat benefits compared to stream reaches without any trees.

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